Evaporation Duct Heights (Measured vs the Bulk Method)

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INTRODUCTION

Knowledge of properties of the atmosphere immediately above the sea is becoming more important as the radar cross sections of threats become smaller and as the surveillance radar frequencies become higher. It is important to identify operational methods for obtaining the required METOC descriptions and the impact of knowing them. Current Tactical Decision Aids relate sensor performance to atmosphere and ocean surface properties and with the output from these TDA's mission plans can shifted with regards to time of execution , types of platform used during a mission and actually re-route of infil and exfil of personnel. This is made relevant when detecting low-flyers or small fishing vessels in ship-defense operations (USS COLE, small fishing vessel hitting the USS Kennedy). As these threats became faster and/or their Radar Cross Section are decreased, the

warfighter has to include the consideration of atmosphere and ocean surface effects on radar-based weapon systems to achieve ship-defense.

BACKGROUND

Since radar is the detection sensor in question, measured or predicted air flow properties have to be identified as being important. Radar propagation in the atmosphere is dependent on the vertical gradient of the modified index of refraction, M (or modified refractivity). M is a function of pressure (p), temperature (T), and the partial pressure of water vapor (e). Strong humidity gradients over the surface of the ocean can cause refraction gradients that trap electro magnetic (EM) waves immediately above the surface, in the atmospheric surface layer. This phenomenon is known as evaporation ducting. Evaporation ducting greatly increases radar frequency propagation distances in relation to standard atmosphere. Greatly increased surface clutter is another feature, in addition to extended radar range, that arises due to the trapping.

Various instruments are used to determine the atmospheric parameters of p, T, and e and determine the M

profile is produced. Since most instruments have inherent difficulty in precise measurements near the surface, a bulk method (Fairall, et. al, 1996) was derived to approximate these parameters. The bulk method is based on measurements at a single level and the sea surface and is used to approximate the M profile.   The data from the R/V Point Sur's summer 04 cruise was put together: to evaluate bulk methods by taking measuring profiles of p, T and e using a radiosonde flown from a kite and static sensors on a boat and comparing it to evaluate the output for the bulk method.

The atmospheric parameters that are important to radar detection and its effects on refraction of EM energy are well known, predicted and analyzed routinely. Therefore, there was no question on what variables to measure in this field-based study. How to get the necessary atmospheric properties from measurements was a whole other issue. An atmosphere's index of refraction, n, determines the phase speed of electromagnetic waves and therefore the different phase speeds along individual wave fronts. The value of n is very close to 1, so to modify and make the variable more useful, the refractivity variable N is used instead, where $N=(n-1) \times 10^6$. Actual values of N are not as important in most applications as the gradient of N with respect to

height, dN/dz. Table 1 illustrates the relationship between dN/dz and propagation ranges.

Class	dN/dz	Propagation Range
Subrefraction	$dN/dz > 0$ m^{-1}	decreased
Normal	0 $km^{-1} > dN/dz > -.079$ m^{-1}	normal
Superrefraction	$-.079 m^{-1} > dN/dz > -.157$ m^{-1}	increased
Trapping (ducting)	$dN/dz < -.157$ m^{-1}	greatly increased

Table 1.   Classes of Refraction

It is difficult to identify ducting regions from a simple visual inspection of a profile of N. The use of modified refractivity (M) resolves this difficulty, where $M=N+(0.157$ $m^{-1})z$ and z is the height above the surface in meters. Ducting occurs when $dM/dz < 0$, making ducting regions easily discernable.
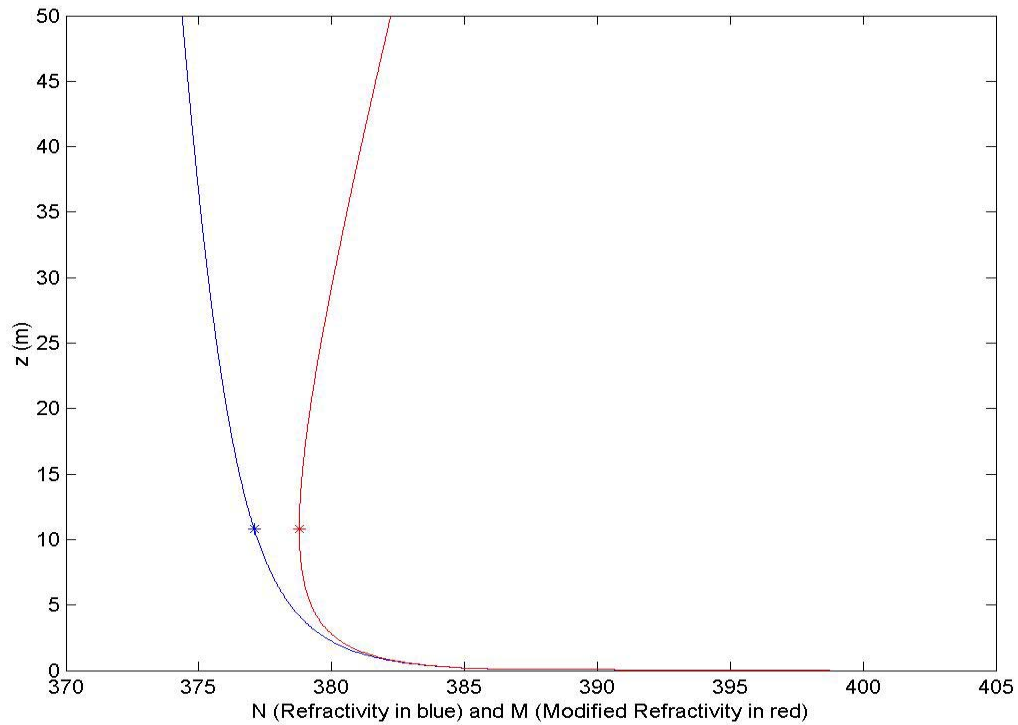
Figure 1.   Comparison of refractivity (N) and modified refractivity (M) illustrating how useful modified refractivity is in identifying the transition from superrefraction to trapping (ducting). This height is marked by an asterisk and is called the duct height.

The term evaporation duct arises because surface evaporation is associated with the strong humidity gradient responsible for the ducting. The level at which dM/dz = 0 is the evaporation duct height. Sea surface temperature, although not an airflow property, plays an important role in evaporation duct characteristics because the vapor pressure at the surface is strongly dependent on water temperature. M as a function of pressure, air temperature

and vapor pressure (the latter derived from relative humidity and air temperature) is given by:

$$M = 77.6\frac{p}{T} - 5.6\frac{e}{T} + 375000\frac{e}{T^2} + 0.157z$$

Most operational situations do not allow for direct profile measurements of e, T and p, and therefore M. In these cases the use of bulk methods are used to estimate the profiles

Monin-Obukhov theory states that vertical gradients of temperature ($\frac{\partial T}{\partial z}$) and specific humidity ($\frac{\partial q}{\partial z}$) in the surface layer depend on scaling parameters related to the turbulent vertical fluxes of momentum, sensible heat and latent heat (moisture). Monin-Obukhov scaling parameters are determined by measurements at two levels, the surface and an arbitrary reference height (z) within 20 meters of the surface. Specific parameters are the sea surface temperature (SST), an assumed sea surface humidity of 98% and reference height temperature (T_{air}), humidity and wind speed. Values subscripted with asterisks are scaling parameters, κ is the von Karman constant (0.4), g is the acceleration of gravity, (ψ)is the stability function, and L is the Obukhov length scale.

$$T_* = (T_z - T_s)\kappa[\ln(\frac{z}{z_{oT}}) - \psi_T(\xi)]^{-1}$$

$$\xi = \frac{z}{L}$$

Once the scaling parameters are determined, the gradients can be calculated using equations similar to the equation for the temperature gradient, $\frac{\partial T}{\partial z} = \frac{T_*}{\kappa z}\Phi(\frac{z}{L})$, where Φ is a stability function determined experimentally over land (Fairall, et. al, 1996 and Davidson, 2002). The important feature of these predictions is that the relative influence of METOC parameters differs between times during unstable (T_{air}-SST <0) and stable (T_{air}-SST >0) conditions. For example, the predicted EDH is influenced primarily by air-surface humidity (RH) and wind speed for an unstable atmosphere and by Tair- SST value and wind speed for stable conditions.

Refractive conditions affecting detectability of surface targets can be more complex than the influence of the evaporation duct. The key component of any duct is a trapping layer, in which dM/dz < 0 or dN/dz < -.157 $m^{-1.}$

The NPS designed a kite-borne radiosonde system, aimed at measuring the atmospheric surface layer, from near surface (1 meter) up to approximately 100 meters. The Vaisala (Omega or Loran) sonde can be attached to the kite and measures vertical profiles of pressure, temperature and vapor pressure, the determining parameters for EM propagation, in two-second intervals. We found in initial flight that the Omega sonde were a little more noisy than the Loran sonde's which made using the Omega sondes data useless for the comparison . The kite sonde was released behind the boat with enough slack to stay about 1 meter off the surface. Once the kite sonde had reached a distance of approximately 100 meters away from the ship, it was manipulated to rise slowly to a height of approximately 100 meters. At that point, the kite sonde would be reeled back in toward the boat to a height of 1 meter and the process was repeated until Professor Guest told us it was done. Generally, sonde batteries last for two hours, providing numerous vertical profiles for each sonde.

The vessel mounted sensor and kite-borne radiosonde data collected for the radar detection tests have unique and interrelated roles to play. The boat data is continuously collected throughout the field test and is considered the actual environmental condition. Bulk

methods applied to the boat data provide the actual vertical M profile of the lower atmosphere. As described previously, the bulk method is a model-based calculation of the vertical M profile based on meteorological data at the surface and a level above the surface. Such a model works best under stationary and horizontal homogeneous conditions. These conditions often do not exist in dynamic regions just offshore, as was the San Clemente Island location. The main purpose of kite data is to verify that the bulk method is a viable mean to determine vertical M profiles. Therefore, the kite data were measured in situ and used to provide credence to the bulk method approach. The bulk method was the only practical method to get the continuous METOC description for the continuous and spatial varying vessel signature tests. Results of the bulk predicted versus kite-borne radiosonde derived profile comparison will lead to conclusions as to the validity of the model predictions relative to METOC profiles.
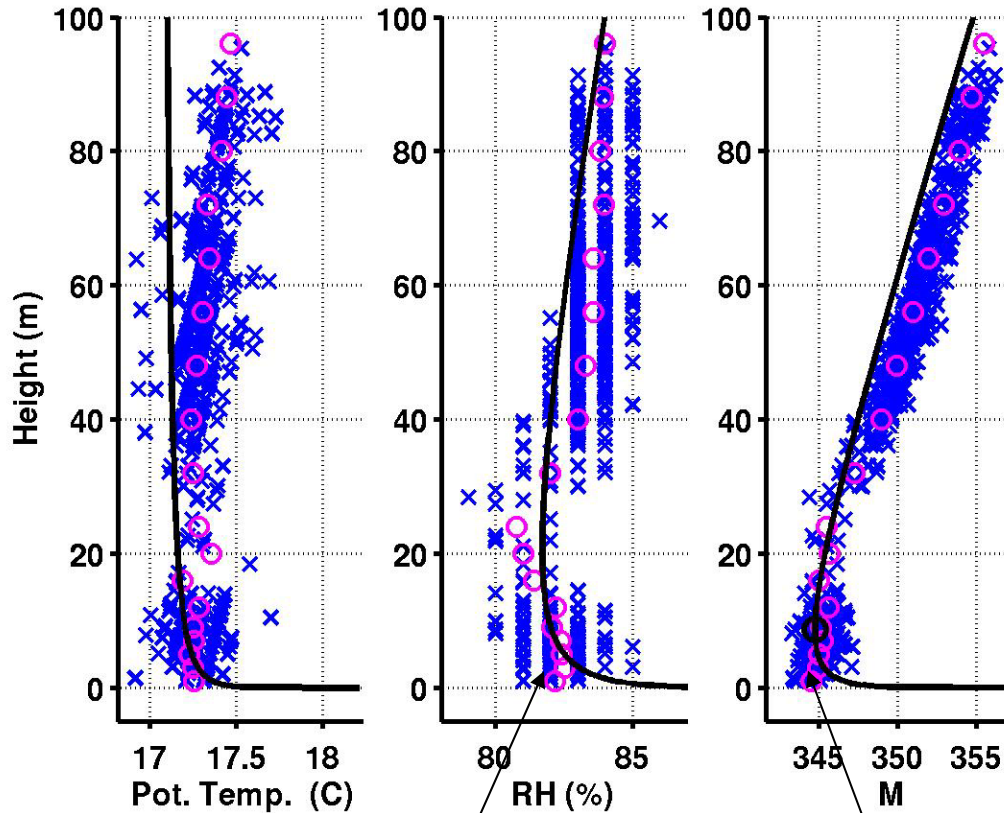
DATA

The field test took place over 4 non-sequential days and useful kite sonde data were obtained. This data was then inputted into a MATLAB program provided by Professor Peter Guest to analysis the Kite/Tethered sonde. The program

allowed the user to manipulate data so as the correct for erroneous minimum heights, take out data that might have been contaminated and make a best fit with the bulk derived profile so as to compare the bulk-derived profile with a representation of the kite-borne sonde measured values to see if there is any validity to the bulk method. The first two attempts at flying the kite proved to have little benefit to the experiment, the Omega sonde that was used which lead to a noise return when measuring the pressure, also the student dunked the Sonde twice during the flights. The third flight proved to be better because a Loran GPS sonde was used this data seem cleaner then the two previous flights the kite was dunked there as well. The last flight again we used the Loran that gave more usable data, the kite survived the entire run. The figure below shows the data collected from the Loran sonde. The green lines indicate data from the R/V Point Sur's Serial ASCII Interface Loop (SAIL) system which is located approximately 17 meters from the sea. The blue line indicate data from the Sonde.
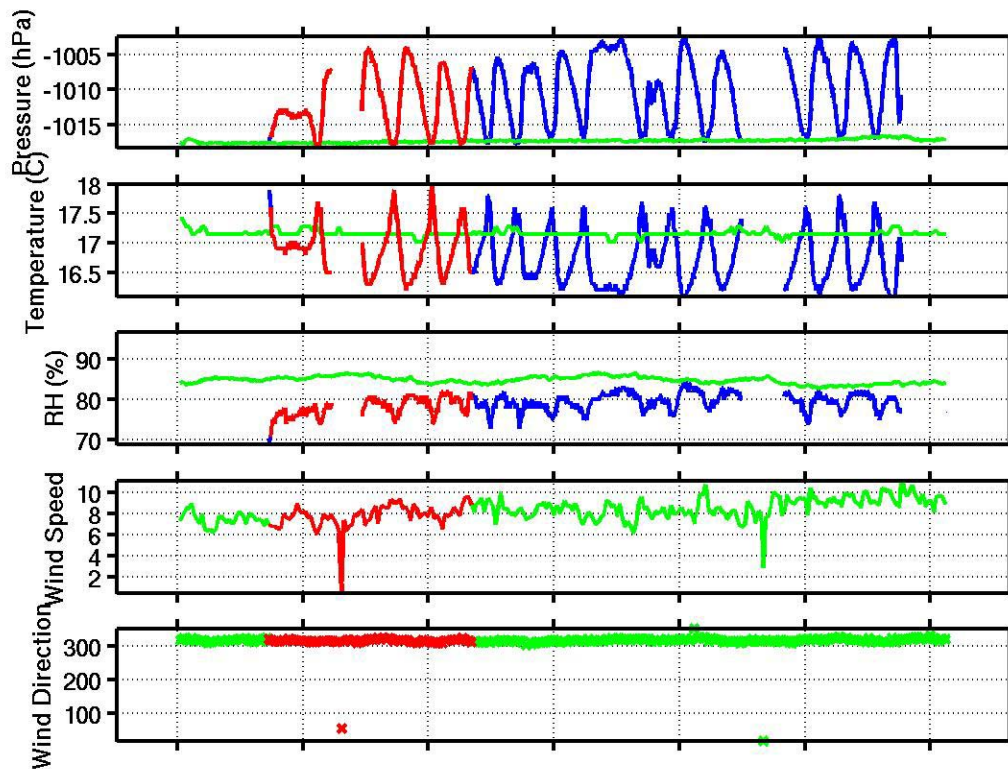
Looking at the figure below; when comparing the kite data to the bulk derived data there was a decrease in Relative Humidity (RH) as the sonde data approached the surface. This went against one of the bulk method's primary assumptions that as the vertical profile approaches the surface the RH increases with decreasing height near the surface and just above the sea surface the RH equals 98%. Most kite flight had this same result and was determined that the bulk method and actual data did not agree below approximately 5 meters.

RH DECREASING WITH HEIGHT
which leads to M values to decrease with height

CONCLUSIONS

At this time it was determined that the data must have been contaminated near the surface at which time it was decided to remove the data that was related to when the sonde approaching the ship. It was feared that the data from the sonde as it was reeled back into the ship was being contaminated by the heated air coming from the ships stack.

The figure below shows what the data looked like after the "bad data" was removed.
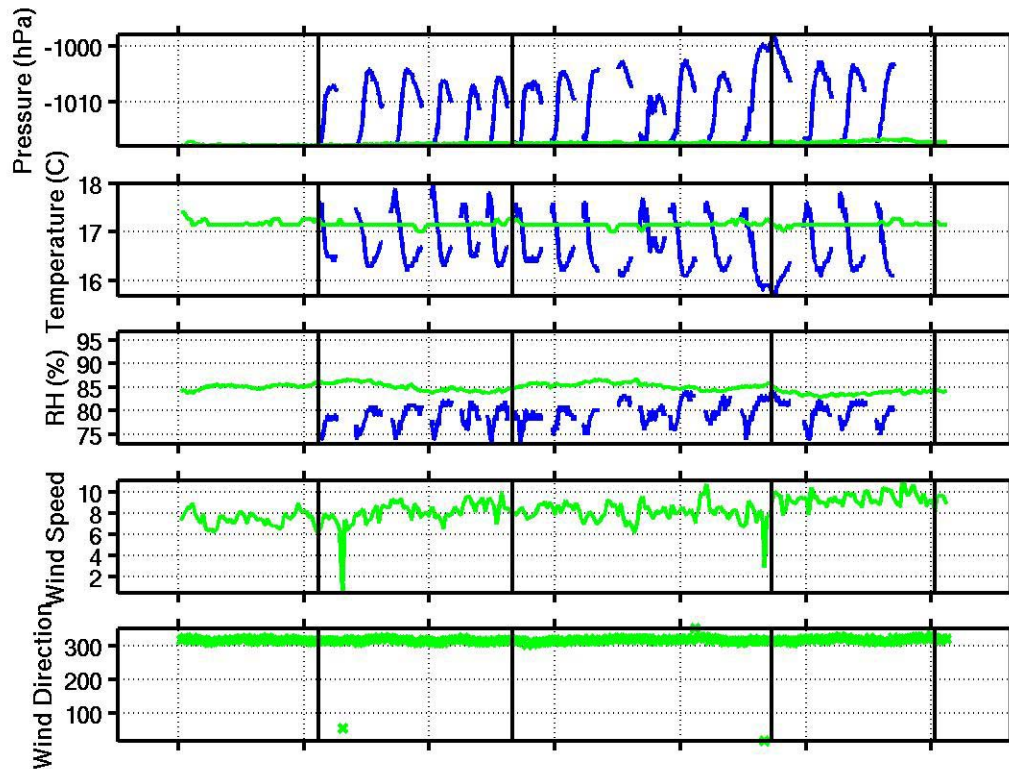
Once this was achieved the the kite data was again compared to the bulk derived curve. The figure below shows that the RH increases with height and the M profile follows the bulk method curve.
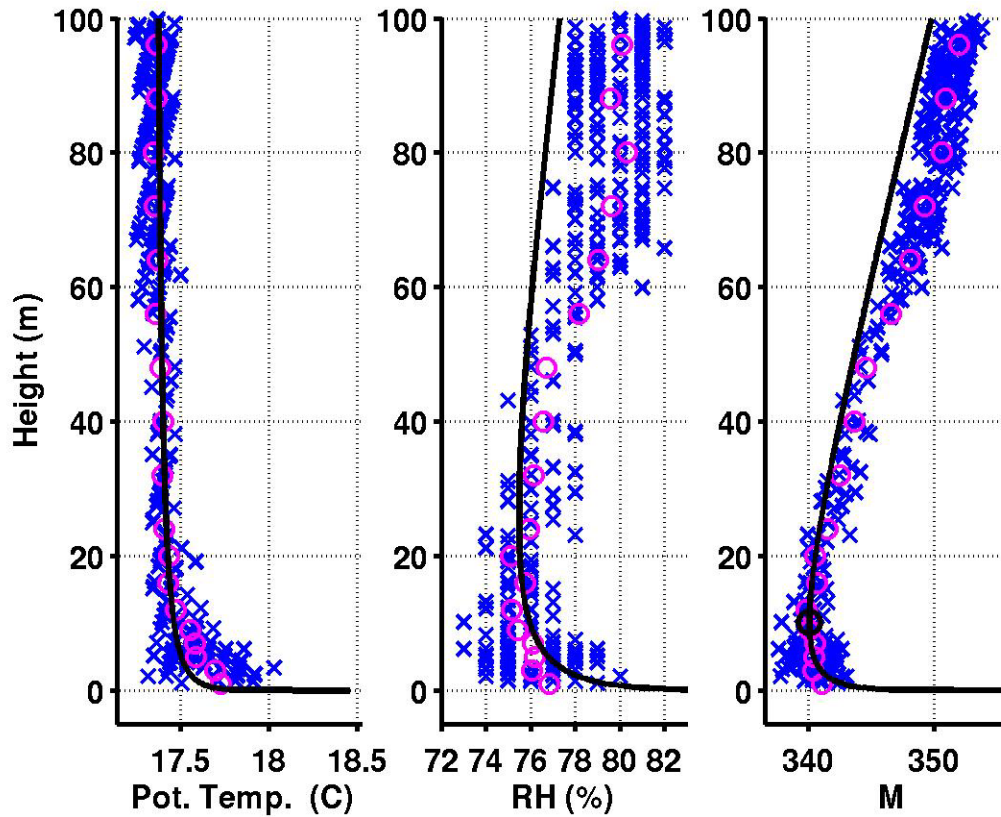
When comparing the kite sonde profiles and the smooth bulk method profiles, it is important to note that the slope of the modified refractivity profiles, not the values themselves are important in determining propagation, even though the figures show a best fit of the bulk method to the kite data the actual bulk curve would have appeared to the right of the kite data. In general, the kite profile and the bulk method profile are in good agreement above 5 meters. But below 5 meters in some cases, the bulk method profiles still exhibit stronger negative gradients than the kite sonde profiles. Kite-sonde profiles in this near-

surface region are influenced by height assignment, sampling, and boat contamination errors, human error, sonde error due to stabilization time and until there is a better way of measuring environment this will remain a problem.

ACKNOWLEGEMENTS: